Appendix L. Vital-Sign Evaluation and Selection Process

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Contents

Introduction 2

Delphi Survey – Overview 2

Organization of the First-Round Delphi Survey 4

Response to First-Round Delphi Survey 5

Organization of the Second-Round Delphi Survey 7

Response to Second-Round Delphi Survey 12

Pre-Workshop Vital-Sign Evaluation Survey 13

Response to the Survey 19

Vital-Signs Workshop 19

Workshop Process and Outcomes 21

Workshop Challenges and Issues 23

Post-Workshop Follow-Up and Synthesis 24

Introduction

This Appendix summarizes the process used by the Northern Colorado Plateau Network (NCPN) to identify, evaluate, and select potential vital signs for monitoring. This process involved an internet-based Delphi survey, a vital-sign evaluation exercise (hereafter referred to as the "pre-workshop survey"), a vital-signs evaluation workshop, park visits and scoping, and information synthesis.

In addition to on-going literature review, all phases of this process were informed by scoping activities associated with the Phase I report (Evenden et al. 2002). The NCPN monitoring-needs database, developed on the basis of substantial input provided by park staff (see p. 17 and Appendix H of Phase I report), was used throughout the vital-signs identification process to ensure that previous park input was fully represented. Similarly, the synthesis of park management and monitoring issues presented in Appendix O of the Phase I report was a key information source that informed the vital-signs process. The report from the geoindicators workshop held in Moab during June 2002 (Appendix H, Phase II report) was another important element of Phase I scoping that was used to inform the vital-signs identification process.

Delphi Survey – Overview

The NCPN contracted with the University of Idaho to conduct an electronic, internet-based Delphi survey to obtain input from experts regarding the design of vital-signs monitoring in the 16 NPS units of the NCPN. The Delphi technique "...may be characterized as a method for structuring a group communication process so that that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem" (Linstone and Turoff 1975:3). The Delphi method has been used elsewhere as an approach for obtaining input on the design of resource monitoring programs (e.g., Davis 1997; Oliver 2002a, b).

In cooperation with the University of Idaho, the NCPN conducted two rounds of internet-based Delphi surveys in which participants were asked to provide input to the identification of NCPN vital signs. The first round began by introducing goals of the program, explaining key concepts, and briefly describing the parks, their resources, and perceived threats. The first survey introduced a general, conceptual framework that has been adopted by the NCPN for considering monitoring needs (the Jenny-Chapin model; see Phase I report). Following the presentation of this background information, input from the participants was solicited regarding measurable ecosystem attributes to be considered as potential indicators for monitoring the health of terrestrial, riparian, wetland and aquatic ecosystems managed by NCPN parks. In addition, near the end of the survey input was solicited regarding measurable attributes and potential indicators for monitoring the condition of other natural resource values including paleontological resources, night skies, and soundscapes.

The objective of the first round was the generation of ideas – analogous to an electronic “brain-storming session” (Oliver 2002a). Participants were told that the estimated time commitment for completing the first-round survey was from 30 minutes to 1 hour, depending on the scope of their expertise and comments.

In the second round of the electronic survey, participants were presented with summarized first-round results and they were asked to evaluate and prioritize potential indicators or suites of indicators on the basis of several criteria pertaining to conceptual relevance, feasibility of implementation, response variability, and interpretability and utility (e.g., Kurtz et al. 2001). They were told that estimated time commitment for completing the second-round survey would be 1-2 hours. They were also told that these surveys were just one means by which the NCPN was acquiring input for monitoring design. Other means included targeted discussions with individual subject-matter experts and resource-management professionals, workshops, and literature reviews. Finally, participants were told that they had been invited to participate in the surveys because of their expertise pertinent to long-term ecological monitoring in NCPN parks.

Administration of the Delphi Survey

On January 26, 2003, the first round of the Delphi survey was sent via email to 237 scientists and natural resource experts to provide input to the NCPN Vital Signs Monitoring Program. Within the email was an internet link (http://www.cnr.uidaho.edu/wilderness/NCPN/NCPNSurvey.htm) which recipients could “click” to open the survey in their web browser. The list of invited participants was developed by NCPN to include scientists and resource-management specialists with expertise in ecological monitoring and ecosystems represented in NCPN parks (Table 1). A list of invitees is available on request from the NCPN.

Table 1. Categories of expertise of 237 Delphi-survey recipients.

Categories of technical expertise	**No. of recipients**	**Categories of technical expertise**	**No. of recipients**
Arid-land ecology / monitoring	54	Hanging gardens	4
Forest ecology	18	Climate	3
Vertebrate ecology	19	Air quality	8
Invertebrate ecology	8	Paleontology	16
Riparian ecology	18	Miscellaneous	7
Landscape ecology / remote sensing	18	NCPN Science Panel	6
Aquatic ecology, water quality, and hydrology	40	NPS Park, network, regional staff	18

The survey was developed using Microsoft FrontPage web authoring software. This allowed a web page to be created in which people could enter their answers directly in input fields on the web page and then submit them when they were finished. Their data were instantaneously sent to the University of Idaho FrontPage computer server and appended to an Excel data base. The actual results of the survey were organized, labeled and submitted by the University of Idaho to the NCPN ecologist in the form of detailed spreadsheets.

The rapid speed of collecting information via an internet survey is only one reason the electronic survey format was chosen. The survey also presented a wide variety of background information about the vital signs monitoring program and many considerations specific to the NCPN. Background information presented to participants included definitions of key terms and concepts, an overview of anthropogenic threats to NCPN resources, general monitoring questions of the NCPN, and the general conceptual model adopted by the NCPN for purposes of framing the monitoring program (the Jenny-Chapin model presented in the Phase I report). The majority of this background material was presented via links that would open separate browser windows. Thus participants already familiar with the NCPN program could bypass this information and proceed directly to the input tables. This background material is accessible via the internet link provided above or upon request from the NCPN.

Organization of the First-Round Delphi Survey

The first survey solicited input on five tables that pertained to major categories of ecosystems: (1) arid-semiarid shrubland, grassland, and pinyon-juniper woodland ecosystems, (2) montane shrubland, woodland, and forest ecosystems, (3) riparian and wetland ecosystems, (4) aquatic ecosystems, and (5) landscape-level processes. In each table, three columns were provided in which respondents were asked to identify:

1. The most important ecosystem processes that contribute to these desired ecosystem functions,
2. Measurable environmental attributes that provide insights regarding the functional status of these processes and their capacities for resistance and resilience, and
3. Comments explaining their answers.

Each table also provided the opportunity to identify additional ecosystem functions that could be considered in the monitoring program. Figure 1 is an example showing the ecosystem function and process input tables with sample answers entered.

In the actual survey, respondents could type in answers to any or all of the boxes in the input table. They could also provide answers in any or all of the five ecosystem input tables, depending upon their level of knowledge and expertise.

Arid-Semiarid Shrubland, Grassland, and Pinyon-Juniper Woodland Ecosystems			
Desired ecosystem function	Contributing ecosystem process	Associated measurable attributes (potential indicators)	Comments/rationale for nominating this attribute
Conservation of soil & water resources and conditions (includes soil quality and water quality)	(Write your recommendations below.)	Example:	Example:
	Infiltration of water into soil	Infiltration capacity	Infiltration capacity is a dynamic measure that is impacted by management.
Conservation of characteristic biotic functional groups and native biodiversity	Seed production of native perennial grasses	Ratio of flowering shoots to vegetative shoots	Provides info about reproductive status of taxa that reproduce by seed
Conservation of natural disturbance regimes	Fuel accumulation in fire- adapted ecosystems	Cover, volume, &/or spatial distribution of fuel types	Provides info about likelihood & potential characteristics of fire in ecosystem
Conservation of regional atmospheric resources and conditions (includes climate and air quality)	Circulation of clean air	Spatial & seasonal variations in ozone concentrations	Provides info about air quality status
Other function			

Figure 1. Sample input table from the first round of the Delphi Survey.

<u>Response to First-Round Delphi Survey</u>

Overall, 64 scientists and experts submitted completed internet surveys in the first round of the Delphi survey. This was considered an acceptable response for several reasons. First, in a Delphi survey it is common practice to send the survey to a large number of people who may have either relevant experience or expertise in a particular scientific field or who may have worked or conducted scientific studies in a particular park (i.e., one of the 16 parks in the NCPN). The survey asked people who had specific or relevant experience to participate. Many recipients responded that they believed that they did not have the level of expertise or particular knowledge in the NCPN parks that they felt was needed to complete the survey. Others responded that it had been quite a few years since they had conducted studies in these parks. Still others indicated that they could not meet our deadline for responding to the survey. This is acceptable and expected in a Delphi survey because the purpose of the survey is to collect detailed and informed responses from a wide range of people with specific relevant expertise (not to collect representative information from a general population). Furthermore, the response rate was limited by the relatively short deadline to which they were asked to respond. A number of people sent email responses explaining that because of other work assignments or responsibilities they could not respond by the deadline, and some requested to be given the opportunity to participate in the second round.

Survey recipients were asked to limit their response to only those questions within the topic or category of their expertise. The results show that most of the scientists who responded primarily limited their responses to only one or two categories for which they had expertise.

Another way to judge the adequacy of response is to examine the range of expertise represented by the respondents. Table 2 shows that the 64 respondents reported that they had technical expertise in more than 17 different fields, with most listing more than one type of expertise. Arid-land ecology and ecology of invasive exotic species were the two fields identified most frequently.

Table 2. Fields of technical expertise reported by respondents to the first Delphi survey.

Fields of Technical Expertise	**N**	**Fields of Technical Expertise**	**N**
Arid-land ecology	25	Ecology of invasive exotic species	20
Forest ecology	7	Landscape ecology	15
Riparian ecology	16	Population ecology (vertebrates)	11
Aquatic ecology	15	Population ecology (plants)	6
Air quality	3	Remote sensing	4
Climate	7	Resource management	14
Botany	12	Wildlife biology	11
Entomology	7	Monitoring theory	12
Soils / soil ecology	13	Other	18
		TOTAL RESPONDENTS*	64

*Respondents could check more than one field of expertise.

Respondents also were asked to indicate their professional position or status in one or more of six categories. These data are presented in Table 3. About two thirds (62%) were academic scientists or federal government scientists. A much smaller proportion consisted of federal or state resource managers (13.9%) or state government scientists (5.1%). In summary, some 64 scientists with expertise in 35 different fields and from 7 categories of professional employment responded. Therefore, the first round of the Delphi survey can be judged to be quite successful.

Table 3. Professional status of respondents to the first Delphi survey.

Professional Status	Percent	N
Academic scientist/researcher	30.4	24
Federal government scientist	31.6	25
State government scientist	5.1	4
Park or network staff (NPS NCPN)	6.3	5
Federal resource manager	11.4	9
State resource manager	2.5	2
Other	12.7	10
Total	100	79

As indicated above, actual results of the survey were organized, labeled and submitted by the University of Idaho to the NCPN ecologist in the form of detailed spreadsheets. Raw survey results are available upon request from the NCPN. Survey results were synthesized and summarized by the NCPN ecologist, and these synthesized results formed the basis of the second Delphi survey.

Organization of the Second-Round Delphi Survey

On March 4, 2003, the same set of 237 scientists and resource-management specialists were invited to participate in the second round of the NCPN Delphi survey. In the second-round survey (http://www.cnr.uidaho.edu/wilderness/NCPN/NCPN2ndSurvey.htm), recipients were presented with a categorized set of 312 environmental attributes and measures for consideration as candidate vital signs. The master list of candidate vital signs was synthesized from scientific literature and input provided during the first-round Delphi survey. Table 4 presents the framework used to organize candidate vital signs in the second survey. SeeTable 5 at the end of this Appendix for a full list of attributes and measures.

Table 4. Monitoring themes and associated categories of candidate vital signs considered in the second Delphi survey.

MONITORING THEME	VITAL SIGNS CATEGORY (n = number of candidate vital signs)	EXPLANATION
Ecosystem structure & function	Climate (15)	Abiotic & biotic indicators of climatic/ meteorological conditions.
	Air quality (17)	Abiotic & biotic indicators of air quality.
	Upland soil & water resources (41)	Abiotic & biotic indicators of upland (hill slope) hydrologic function, soil quality, soil-site stability, nutrient cycling.
	Upland disturbance regimes (14)	Abiotic & biotic indicators associated with the occurrence, likelihood, or management of fire and insect-related disturbances.
	Upland & riparian communities (38)	Biotic integrity; composition of vascular & nonvascular plant, vertebrate, and invertebrate communities; exotic plants & animals; effects of herbivory.
	Aquatic, riparian & wetland hydrologic/ geomorphic regimes (29)	Abiotic & biotic indicators of hydrologic / geomorphic regimes; hydrologic function; water quantity.
	Water quality (27)	Abiotic & biotic indicators of water quality.
	Aquatic communities (19)	Biotic integrity; composition of aquatic vertebrate & macroinvertebrate communities; exotic plants & animals.
	Landscape-level patterns (16)	System dimensions, connectivity, fragmentation, land-use & land-cover patterns.
Species/populations of concern	Species/populations of concern (40)	Threatened, endangered, rare, or endemic species; species otherwise of concern / interest.
Other natural resource values	Other natural resource values (14)	Paleontology, wilderness experience, solitude, dark night sky, natural soundscape, river-running hazards & campsites.
Stressors	Stressors (42)	Candidate vital signs for active monitoring of stressors impacting park natural resources, if not already included in other categories.

Participants were asked to review the subset of environmental attributes that fell within the scope of their professional expertise and to evaluate them as potential vital signs on the basis of four general evaluation criteria derived from NPS Inventory and Monitoring Program guidance and scientific literature[1]:

[1] Key sources for evaluation criteria: Kurtz et al. (2001), Tegler and Johnson (1999), Dale and Beyeler (2001), Herrick et al. (1995, 2002), Noss (1990), Whitford (1998, 2002), Pyke et al. (2002).

1. Management Significance & Utility. Vital signs must provide information that is meaningful and useful to park managers. The following statements describe vital-sign characteristics pertinent to this criterion:

    - Relevant to management issues and concerns;
    - Provides information useful for management decisions;
    - Sensitive to particular stressors affecting park resources, OR vital sign itself is a stressor or driver of resource change and variability;
    - Predicts changes in resource conditions that can be averted by management actions;
    - Produces results that are easily communicated and clearly understood and accepted by scientists, policy makers, managers, and the public;
    - Produces results with recognizable implications for stewardship, regulation, and/or research;
    - If associated with species-level (or population-level) monitoring, vital sign is an attribute of a species that is legally protected, endemic, harvested, alien, or otherwise of special interest or concern;
    - Can be applied across a wide range of ecosystems and ecosystem conditions (i.e., is not restricted in application to a particular site or system).

2. Ecological Significance & Scientific Validity. Vital signs must be ecologically significant and clearly justified on the basis of peer-reviewed literature and a scientifically sound conceptual framework. The following statements describe vital-sign characteristics pertinent to this criterion:

    - Relevant to the ecological function or valued natural resource it is intended to represent, OR vital sign itself is a stressor or driver of resource change and variability;
    - Peer-reviewed literature exists to support relevance of the vital sign;
    - For ecosystem-level monitoring, vital sign reflects functional status of one or more key ecosystem processes or the status of ecosystem properties that are clearly related to these ecosystem processes [Note: replace term *ecosystem* with *landscape* or *population*, as appropriate];
    - For ecosystem-level monitoring, vital sign reflects the capacity of key ecosystem processes to resist or recover from change induced by natural disturbances and/or anthropogenic stressors [Note: replace term *ecosystem* with *landscape* or *population*, as appropriate];
    - Signifies impending change in the ecological system (i.e., is anticipatory);

3. Feasibility & Cost of Implementation. Sampling, analysis, and interpretation of vital signs must be technically feasible and cost-effective. For purposes of vital-sign evaluation, a cost-effective vital sign is defined as one with a high benefit:cost ratio – i.e., information benefits are high relative to total costs. The following statements describe vital-sign characteristics pertinent to this criterion:

    - Well-documented methods exist;

- If well-documented methods do not exist, development is technically feasible and cost-effective;
- Logistical requirements are feasibly met (includes training, travel and site accessibility, sampling time per measurement and for the number of required replicates, sample transport, sample processing and analysis, etc.);
- Full costs of implementation are low relative to benefits gained from information (includes costs associated with protocol development and pilot studies, long-term sampling, instrumentation, analysis, data management, etc.);
- If specialized knowledge and/or instrumentation is required for data acquisition or analysis, benefits gained are high relative to costs associated with specialized knowledge and instrumentation;
- Sampling does not significantly impact the site or protected organisms (i.e., is nondestructive);
- Sampling does not significantly affect subsequent measurements of the same parameter or simultaneous measurements of other parameters.

4. Signal:Noise Ratio (Response Variability). Vital signs must be characterized by patterns of variability that are well understood and possess a high signal:noise ratio. That is, variability attributable to anthropogenic stressors must be high relative to variability attributable to natural processes or measurement errors. The following statements describe vital-sign characteristics pertinent to this criterion:

   - Vital sign has limited and documented sensitivity to natural variation;
   - Measurement errors introduced by human observers and/or instruments during data collection, transport, analysis, and management can be controlled and estimated;
   - Factors driving short-term temporal variability are understood (including natural drivers and anthropogenic stressors) and can be estimated and evaluated;
   - Factors driving long-term temporal variability are understood (including natural drivers and anthropogenic stressors) and can be estimated and evaluated;
   - Factors driving spatial variability in data are well understood and can be accounted for via stratification or other means;
   - Vital sign is able to discriminate differences among sites along a known condition gradient, and locations in similar “condition” yield similar measurements;
   - Responds to stress in a predictable, unambiguous manner;
   - Provides continuous assessment over wide range of stress;
   - Discriminatory ability meets data quality objectives, factoring in variability as well as precision and confidence levels desired by the program.

Participants in the survey evaluated candidate measures by assigning them evaluation scores on a scale of 1-5 for each of the four criteria (Table 6). Figure 2 illustrates a sample vital-sign evaluation input form from the second Delphi survey.

Table 5. Evaluation criteria and choices of ratings for candidate vital signs considered in second Delphi survey.

Evaluation Criteria	Choices of Ratings for Each Criterion
Management Significance & Utility	5. EXTREME significance & utility 4. HIGH significance & utility 3. MODERATE significance & utility 2. SLIGHT significance & utility 1. NO significance & utility No Answer
Ecological Significance & Scientific Validity	5. EXTREME significance & validity 4. HIGH significance & validity 3. MODERATE significance & validity 2. SLIGHT significance & validity 1. NO significance & validity No Answer
Feasibility & Cost of Implementation	5. EXTREMELY feasible & cost effective 4. HIGHLY feasible & cost effective 3. MODERATELY feasible & cost effective 2. SLIGHTLY feasible & cost effective 1. NOT feasible & cost effective No Answer
Signal:Noise Ratio (Response Variability)	5. EXTREMELY HIGH signal: noise ratio 4. HIGH signal: noise ratio 3. MODERATE signal: noise ratio 2. LOW signal: noise ratio 1. UNACCEPTABLY LOW signal: noise ratio No Answer

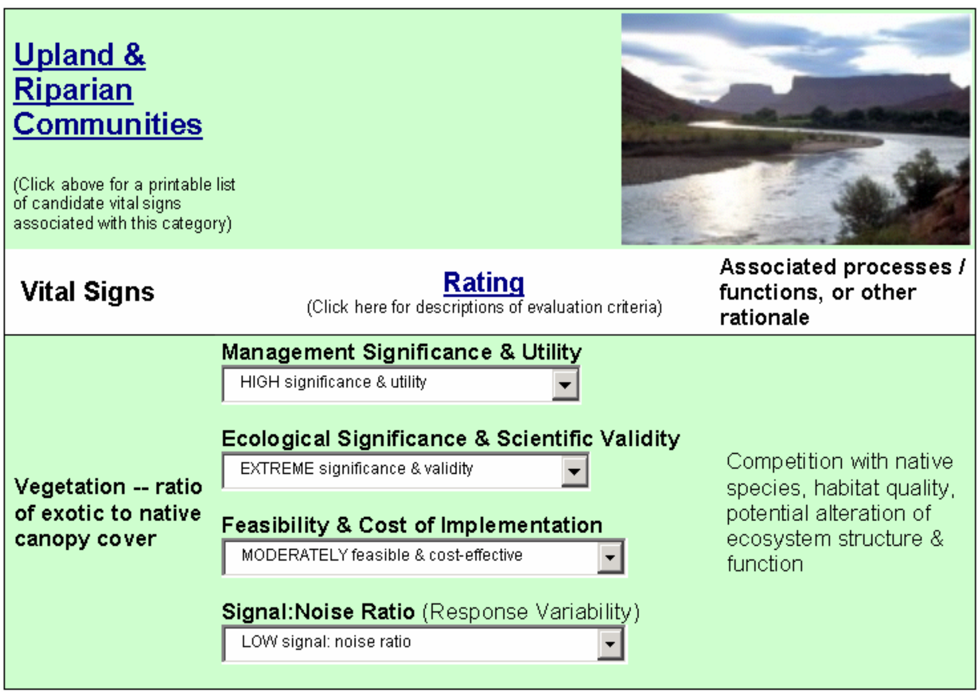

Figure 2. Sample input form from the second Delphi survey.

General monitoring questions posed by NCPN parks provided the context for the evaluation of candidate vital signs (see pp. 62-63 of Phase I report, Evenden et al. 2002). Respondents could review these general monitoring questions by clicking on a link in the internet survey. Additional background material including program goals, definitions of key concepts (e.g., ecosystem health), and a description of the general ecosystem model adopted by the NCPN accompanied the first round of questioning and could also be seen by clicking on a link in the second survey.

Response to Second-Round Delphi Survey

Seventy-two scientists and experts submitted completed internet surveys in the second round of the Delphi survey. Given the complexity, wide distribution, and short time allowance for the survey, this was considered a good response. As in the first survey, recipients were asked to restrict their responses to those candidate vital signs within the scope of their professional expertise. Table 7 shows that the respondents reported that they had technical expertise in more than 17 different fields. Arid-land ecology was again the most frequently cited field of expertise.

Table 6. Fields of technical expertise reported by respondents to the second Delphi survey.

Fields of Technical Expertise	**N**	**Fields of Technical Expertise**	**N**
Arid-land ecology (including rangeland ecology)	29	Ecology of invasive exotic species (plants and/or animals)	15
Forest ecology	10	Landscape ecology	14
Riparian ecology (including fluvial geomorphology of arid-land streams & rivers)	20	Population ecology and monitoring of rare and/or sensitive vertebrates including avifauna, amphibians, mammals, and/or fish	10
Aquatic ecology (including water quality)	16	Population ecology and monitoring of rare and/or sensitive plants	11
Air quality	3	Remote Sensing	3
Climate	4	Resource Management	17
Botany	15	Wildlife Biology	6
Soils and soil ecology	14	Monitoring theory	12
Entomology	11	Other*	14
		TOTAL RESPONDENTS**	72

*Other fields of expertise listed by respondents included such things as paleontology, fire ecology, wetland restoration, chemistry, geology, statistics, and biogeochemistry.
**Respondents could check more than one field of expertise.

Finally, respondents were also asked to indicate their professional position or status in one or more of six categories. These data are presented inTable 8. About two thirds (64%) were academic scientists or federal government scientists. A very small proportion consisted of state government scientists (3.8%) or federal or state resource managers (9%).

Table 7. Professional status of respondents to second Delphi survey.

Professional Status	Percent	N
Academic scientist/researcher	29.5	23
Federal government scientist	34.6	27
State government scientist	3.8	3
Park or network staff (NPS NCPN)	12.8	10
Federal resource manager	7.7	6
State resource manager	1.3	1
Other	10.3	8
Total	100	78

Detailed data displaying the responses to all of the survey questions were compiled by the University of Idaho and submitted to the NCPN ecologist in the form of Excel spreadsheets. On the basis of evaluation scores assigned to candidate vital signs, the NCPN ecologist reviewed input from the second-round survey and used professional judgment to reduce the candidate set from 312 to 164 attributes or measures. During the review process, it became apparent that survey participants commonly misinterpreted the concept of signal:noise ratio. Consequently, evaluation scores for this criterion were not incorporated in the overall scores used to rank and reduce the candidate set. Raw survey results and evaluation scores for candidate vital signs are available upon request from the NCPN.

Pre-Workshop Vital-Sign Evaluation Survey

In late March and early April 2003, a final round of vital-sign evaluation was conducted in preparation for the NCPN vital-sign workshop scheduled for 7-11 April 2003. The reduced set of 164 candidate vital signs was incorporated in a MS Access database designed to facilitate the evaluation of candidates on the basis of 13 relatively specific evaluation criteria (Table 9). These specific criteria were related to the general criteria applied during the second round of the Delphi survey and, like the general criteria, were derived from scientific literature and NPS Inventory and Monitoring Program guidance. The ultimate purpose of the evaluation exercise was to collect data that would aid the development of network-level vital-sign priorities during the subsequent workshop.

Organization of the Survey

Following examples and guidance provided by NPS Inventory and Monitoring Program staff, USGS staff in Moab designed the NCPN vital-sign evaluation database (1) to facilitate the rapid evaluation of 2132 combinations of 164 candidate vital signs and 13 evaluation criteria, and (2) to capture the data resulting from these evaluations. A key feature of the database was a user-friendly data entry screen that presented an array of contextual information (e.g., vital sign theme, category, and rationale for consideration) and automatically stepped participants through the evaluation process (Figure 3). The MS Access vital-sign evaluation database is available upon request from the NCPN.

On March 24th, 2003, the pre-workshop vital-signs evaluation database was distributed with instructional materials to NCPN network and park staff, key USGS and academic cooperators, and NCPN science-panel members. Participants were asked to evaluate candidate measures by assigning them evaluation scores on a scale of 0-5 for each of the 13 criteria. They also were asked to restrict their evaluations to those candidate measures and criteria that were within their scope of professional knowledge. NCPN parks were asked to submit single consolidated responses for their parks. NCPN network staff, USGS and academic partners, and science-panel members all completed the survey from a network-wide perspective rather than on a park-specific basis.

Table 8 cont.

Table 8. Vital-sign evaluation criteria used by the NCPN during the pre-workshop evaluation exercise and during the April 2003 vital-signs workshop. Unless noted otherwise, for each candidate vital sign (environmental attribute or measure) participants were instructed to score all criteria from 0-5 where 0 indicated total disagreement with the stated criterion and 1-5 reflected differing degrees of agreement from weak (1) to very strong (5). If interpreted as simple yes-no statement, 0=no and 5=yes.

1. MANAGEMENT SIGNIFICANCE & UTILITY		**Explanatory Comments / Considerations**
1.1	Degree of legislative / policy mandate associated with vital sign.	**Scoring approach:** **5.** Required by Endangered Species Act, Clean Water Act, Clean Air Act (Class 1 airsheds), or park enabling legislation that mentions specific resource. **4.** Specifically covered by an Executive Order (e.g., invasive plants, wetlands) or by a specific Memorandum of Understanding signed by NPS (e.g., bird monitoring). **3.** Vital sign is associated with a resource or issue that is specifically covered by a GPRA goal or some type of federal or state law in addition to the Organic Act and other general legislative mandates and NPS Management Policies. **2.** Vital sign is associated with a resource that is specifically mentioned in park General Management Plan or Resource Management Plan (or similar document). **1.** Vital sign is not covered by any of the specific mandates listed above, but is associated with a resource or issue that is covered by the Organic Act, other general legislative mandates, and/or NPS Management Policies. **0.** Applicable, but none of the above. **Not applicable:** Vital signs associated with natural drivers of resource change and variability or anthropogenic stressors.
1.2	Vital sign is pertinent to one or more specific management concerns.	Overlaps with criterion 1.1, but criterion 1.2 should be scored to reflect degree of management concern independent of any specific mandate. Other considerations pertinent to this criterion: Vital sign should be responsive to one or more stressors affecting park resources. There should be an obvious, direct application of the data to a key management decision, or for evaluating the effectiveness of past management actions. If associated with species-level (or population-level) monitoring, vital sign should be an attribute of a species that is legally protected, endemic, harvested, endemic, alien, or otherwise of special interest or concern. Management concern may be attributable to the fact that the resource has high public appeal.
1.3	Vital sign reliably predicts adverse changes that can be averted by management actions.	For purposes of resource protection and management, a vital sign that predicts adverse changes before they occur (i.e., serves as early warning) is more useful than one that reflects adverse changes only after they have occurred. (Some vital signs may do both.) Likewise, a vital sign that predicts changes that can be averted by management actions is more useful than a vital sign that predicts changes that cannot be averted by management. Ideally, vital signs that indicate resource conditions should be responsive to management actions within a relatively short period of time.
1.4	Vital sign produces results (data & interpretations) that are easily	Vital signs that are easily communicated and understood may have greater

Table 8 cont.

	communicated, easily understood, and accepted by scientists, policy makers, managers, and the general public, all of whom should recognize implications of vital signs results for protecting and managing the park's resources.	management utility than those that are not.
2. ECOLOGICAL SIGNIFICANCE & SCIENTIFIC VALIDITY		**Explanatory Comments / Considerations**
2.1	Vital sign reliably reflects the status of key ecosystem processes or properties. **OR** if vital sign represents a stressor or natural driver of ecosystem change, then the stressor / driver strongly affects functioning of one or more critical ecosystem processes / properties.	**NOTE:** Replace term *ecosystem* with *landscape, population, or other resource* as appropriate. Relationship between vital sign and associated process or property should be supported by peer-reviewed literature.
2.2	Vital sign reflects the capacity of critical ecosystem processes to resist or recover from change caused by natural disturbances and/or anthropogenic stressors.	**NOTE 1:** Replace term *ecosystem* with *landscape, population* or other *resource* as appropriate. **NOTE 2:** Vital signs that represent anthropogenic stressors or climate should be scored as **Not Applicable**.
2.3	Vital sign is anticipatory -- i.e., reflects an impending change in key components or functions of the ecosystem or other natural resource.	Similar to criterion 1.3, a vital sign that predicts or anticipates impending ecological changes is more useful than a vital sign that reflects ecological changes only after they have occurred.
3. FEASIBILITY & COST OF IMPLEMENTATION		**Explanatory Comments / Considerations**
3.1	Vital sign can be cost-effectively measured.	Consider technical / logistical feasibility, availability of existing methods, and full costs of methods development and implementation (includes training, instrumentation, preparation time, travel & site accessibility, sampling time, sample transport, sample processing & analysis, long-term data management, etc.). Benefits (information value) gained from vital sign should be high relative to total costs incurred. The most cost-effective vital sign is that which indicates the most (in terms of overall resource condition) for the least cost.
3.2	Measurement of vital sign is nondestructive.	Measurement of vital sign should not impact site conditions or protected organisms. Measurement should not affect simultaneous measures of other vital signs or subsequent measures of the same vital sign.
4. RESPONSE VARIABILITY		**Explanatory Comments / Considerations**
4.1	Measurement of vital sign can repeatedly and reliably sort human-caused changes from natural changes over a wide range of resource conditions.	**NOTE: Default answer for natural drivers (e.g., climate) and anthropogenic stressors is YES.** Other considerations: Measurement of vital sign should be repeatable by different observers and by same observer at a different time. Natural and human factors affecting spatial and temporal variability in the vital sign should be well-understood and reliably differentiated. Vital sign should respond to human factors in predictable, unambiguous manner and should be able to discriminate among sites along a known condition gradient. Vital sign should be capable of providing a continuous assessment over a wide range of stress.
5. EXISTING DATA & PROGRAMS		**Explanatory Comments / Considerations**
5.1	Vital sign has been inventoried or is already monitored **within** park (i.e., baseline data are available).	In general, more data are better (e.g., number of years and/or number of stations) -- but the *quality* of existing baseline data also should be considered in relation to this criterion.
5.2	Vital sign is monitored **outside** of park (e.g., by other agencies or	In general, more data are better (e.g., number of years and/or number of

Table 8 cont.

	regional/national monitoring programs).	stations) -- but the *quality* of existing outside data also should be considered in relation to this criterion.
5.3	Data associated with this vital sign are readily available, shared, and/or can be obtained from elsewhere at minimal expense to I&M program.	Some forms of monitoring may be accomplished by acquiring data from other existing sources rather than from new field measurements.
6. PROGRAM INTEGRATION		**Explanatory Comments / Considerations**
6.1	Integrative – the full **SUITE** of vital signs spans key environmental gradients (e.g., soils, elevation, terrestrial > riparian > aquatic), ecological hierarchy (landscapes, ecosystems, populations), spatial scales, and system characteristics / components (including structure, function, and composition).	Applies to full suite of candidate or selected vital signs rather than to individual vital signs.

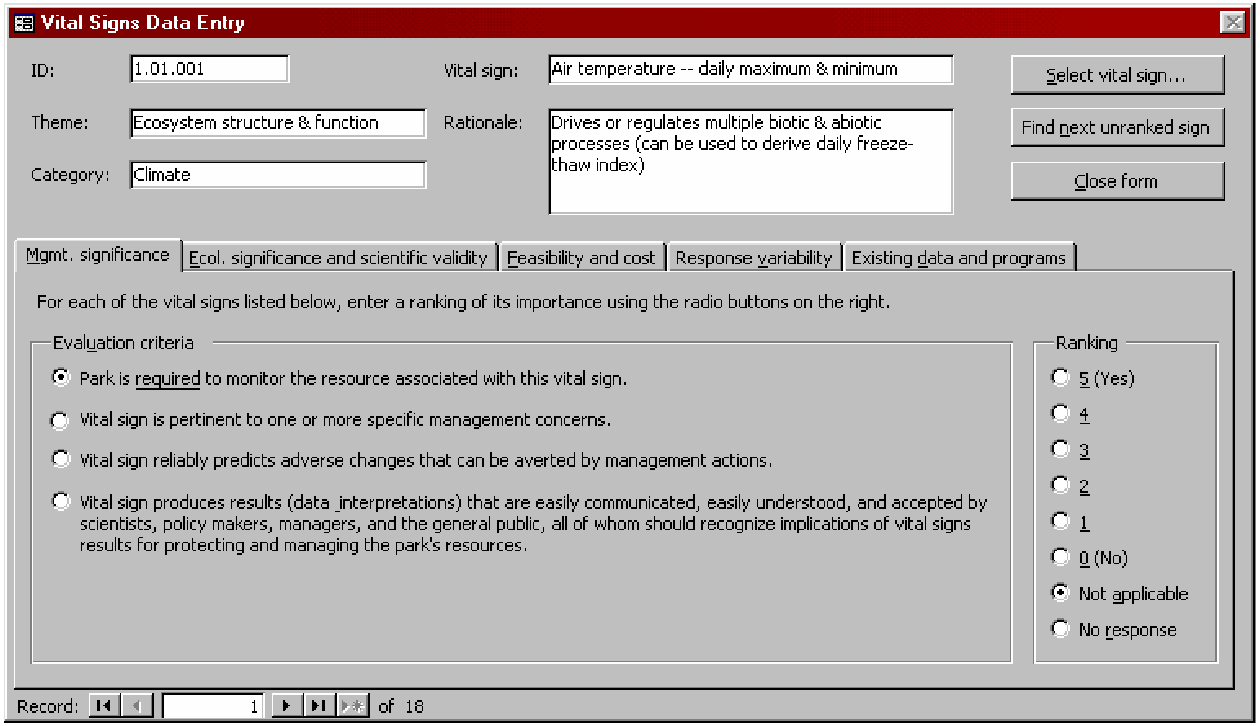

Figure 3. Sample data-input screen from the vital-sign evaluation database used during the pre-workshop vital-sign evaluation survey.

Response to the Survey

Twenty-three parks or individuals participated in the pre-workshop vital-sign evaluation survey (Table 10). An automated process was used to compile the data and calculate average evaluation scores for candidate attributes and measures. For purposes of calculating an overall total evaluation score for each candidate, each of the five criteria categories included inTable 9 (excluding the sixth category) were given equal proportional weight (thus weights varied among individual criteria). On the basis of overall evaluation scores averaged across all survey participants, candidate attributes and measures were ranked *within categories* to form a preliminary prioritization of candidate attributes and measures. This ranked list of candidates was the starting point for vital-sign discussions held during the workshop. In preparation for the vital-sign workshop, survey participants were provided with matrices which summarized their individual (or park) evaluation scores as well as the overall evaluation scores averaged across all participants.

Table 9. Participants in the NCPN pre-workshop vital-sign evaluation survey.

Affiliation	Participants
NCPN parks	Arches National Park
	Black Canyon of the Gunnison National Park
	Bryce Canyon National Park
	Canyonlands National Park
	Capitol Reef National Park
	Cedar Breaks National Monument (completed by Zion staff)
	Colorado National Monument
	Curecanti National Recreation Area
	Hovenweep National Monument
	Natural Bridges National Monument
	Pipe Spring National Monument (completed by Zion staff)
	Zion National Park
NCPN staff and cooperators	Angie Evenden
	Mark Miller
	Elizabeth Nance
	Sonya Daw
	Lynn Cudlip (Western State College, Gunnison, CO)
NCPN science panel members	Buck Sanford, University of Denver
	Tim Seastedt, University of Colorado
	Jack Schmidt, Utah State University
USGS cooperators	Jayne Belnap
	Tim Graham
	Mike Scott

Vital-Signs Workshop

On 7-9 April 2003, a 2 ½ – day NCPN vital-signs workshop was held in Moab. Purposes of the workshop were (1) to review results of the pre-workshop vital-sign evaluation exercise, and (2) to identify network-level vital-sign priorities on the basis of cross-network commonalities in evaluation results and previously identified program emphases. Participants included NPS staff from parks and the network (including managers and technical staff), USGS and academic cooperators, and NCPN science-panel members (Table 11). Water quality vital signs, though included in the Delphi and pre-workshop surveys, were addressed separately during a subsequent two-day workshop on 10-11 April 2003.

Table 10. Participants in the NCPN vital-signs workshop, 7-9 April 2003, Moab.

Name	Affiliation
Adams, Mike	Research Ecologist, USGS-BRD Corvallis OR
Alward, Rich	Ecologist, USGS-BRD Moab UT
Beer, Margaret	Data Manager, NCPN, Moab UT
Belnap, Jayne	Research Ecologist, USGS-BRD Moab UT
Bradybaugh, Jeff	Chief of Resources and Research, Zion National Park, Springdale UT
Cahill, Kelly	Biological Technician, Bryce Canyon National Park, Bryce Canyon UT
Clark, Tom	Chief of Resources, Capitol Reef National Park, Torrey UT
Cudlip, Lynn	Research Associate, Western State College, Gunnison CO
Daw, Sonya	Biologist, NPS NCPN / Southeast Utah Group, Moab UT
Evenden, Angela	Program Manager, NPS NCPN, Moab UT
Graham, Tim	Research Ecologist, USGS-BRD Moab UT
Hiebert, Ron	NPS Research Coordinator, Colorado Plateau Cooperative Ecosystem Studies Unit, Flagstaff AZ
Kim, Sharon	Wildlife Biologist, Zion National Park, Springdale UT
Kokaly, Ray	Geophysicist, USGS-GD Denver CO
Krumpe, Ed	Professor of Resource Recreation and Tourism, University of Idaho, Moscow ID
Kyte, Clayton	Biologist, Fossil Butte National Monument, Kemmerer WY
Louie, Denise	Botanist / Vegetation Program Manager, Zion National Park, Springdale UT
Miller, Mark	Ecologist, NPS NCPN, Moab UT
Nance, Elizabeth	Data Specialist and Biologist, NCPN, Moab UT
Naumann, Tamara	Botanist, Dinosaur National Monument, Dinosaur CO
Noon, Barry	Professor of Fishery and Wildlife Biology, Colorado State University, NCPN Science Panel Member, Fort Collins CO
Price, Dave	Natural Resource Specialist, Colorado National Monument, Fruita CO
Schelz, Charlie	Biologist, NPS Southeast Utah Group, Moab UT
Schmidt, Jack	Associate Professor, Department of Aquatic, Watershed, and Earth Resources, Utah State University, NCPN Science Panel Member, Logan UT
Scott, Mike	Research Ecologist, USGS-BRD, Fort Collins CO
Seastedt, Tim	Professor of Biology, University of Colorado-Boulder, NCPN Science Panel Member, Boulder CO
Sharrow, Dave	Hydrologist, Zion National Park, Kanab UT
Stahlnecker, Ken	Chief of Resource Stewardship and Science, Curecanti National Recreation Area and Black Canyon of the Gunnison National Park, Gunnison CO
Thomas, Lisa	Program Manager, NPS Southern Colorado Plateau Network, Flagstaff AZ
Truett, Joe	Senior Biologist, Turner Endangered Species Fund, NCPN Science Panel Member, Glenwood NM
Wakefield, Gery	GIS Manager, NPS Southeast Utah Group, Moab UT

Workshop Process and Outcomes

During the first half of the workshop, participants discussed average evaluation scores associated with particular measures and evaluation criteria (Table 9). To facilitate the discussion, matrices summarizing overall (average) evaluation scores and individual evaluation scores (i.e., those scores submitted by individual participants in the pre-workshop survey) were digitally projected onto screens at the front of the workshop meeting room. Numerous evaluation scores were revised to reflect group decisions concerning the relative merits of various environmental attributes or measures in relation to the evaluation criteria. After the group reached a consensus regarding the evaluation scores assigned to all of the measures and attributes under consideration, relative weighting schemes were discussed. This discussion focused on whether the five criteria categories (Table 9, excluding the sixth category) should receive equal or different weights in calculating total scores for each candidate, and whether individual criteria should be eliminated or emphasized. To develop a final overall ranking of candidate attributes and measures, the group decided to apply the following relative weights to criteria categories:

- Management Significance & Utility – 35%
- Ecological Significance & Scientific Validity – 35%
- Feasibility and Cost of Implementation – 20%
- Response Variability – 10%
- Existing Data and Programs – 0%

No weight was given to the Existing Data and Programs category because the group decided that candidate attributes or measures should not be "penalized" for not having been monitored in the past. Weights were applied to the consensus evaluation scores, and the resulting overall evaluation scores were used to produce a final ranking of candidate attributes and measures. Table 12 (at the end of this Appendix) presents consensus evaluation scores accepted by the group and candidate vital signs ranked within categories on the basis of overall weighted evaluation scores. Although existing monitoring data and programs did not contribute to overall vital-sign evaluation scores during the April workshop, these did play a significant role in the assignment of park-specific vital-sign priorities presented in the main body of the Phase II report.

To aid group discussion and modification of vital-sign rankings derived from consensus evaluation scores (i.e., Table 12), strips of paper with vital-sign descriptions and scores were posted on the wall of the workshop meeting room (Figure 4). Workshop participants were organized into small workgroups and allowed 1-2 hours to review, rearrange, and annotate posted vital signs. After the workgroup discussions, all participants reconvened as a single group to discuss vital signs on a category-by-category basis. The objective of this discussion was to a agree upon network-level vital-sign priorities informed by evaluation results and previously identified program emphases.

Given budgetary constraints of the program, it was anticipated that the list of network-level vital-sign priorities would be considerably shorter than the full list of measures under consideration. Nevertheless, very few candidate attributes and measures were dropped from consideration during group discussion. Some candidate measures that previously had been trimmed from the list (e.g., following the second Delphi survey) were reconsidered and added back to the list. Table 12 indicates measures retained after workshop. The outcome of the workshop was that the group validated nearly the full list of considered measures as a good set of potential vital signs. However, relative priorities remained ambiguous.

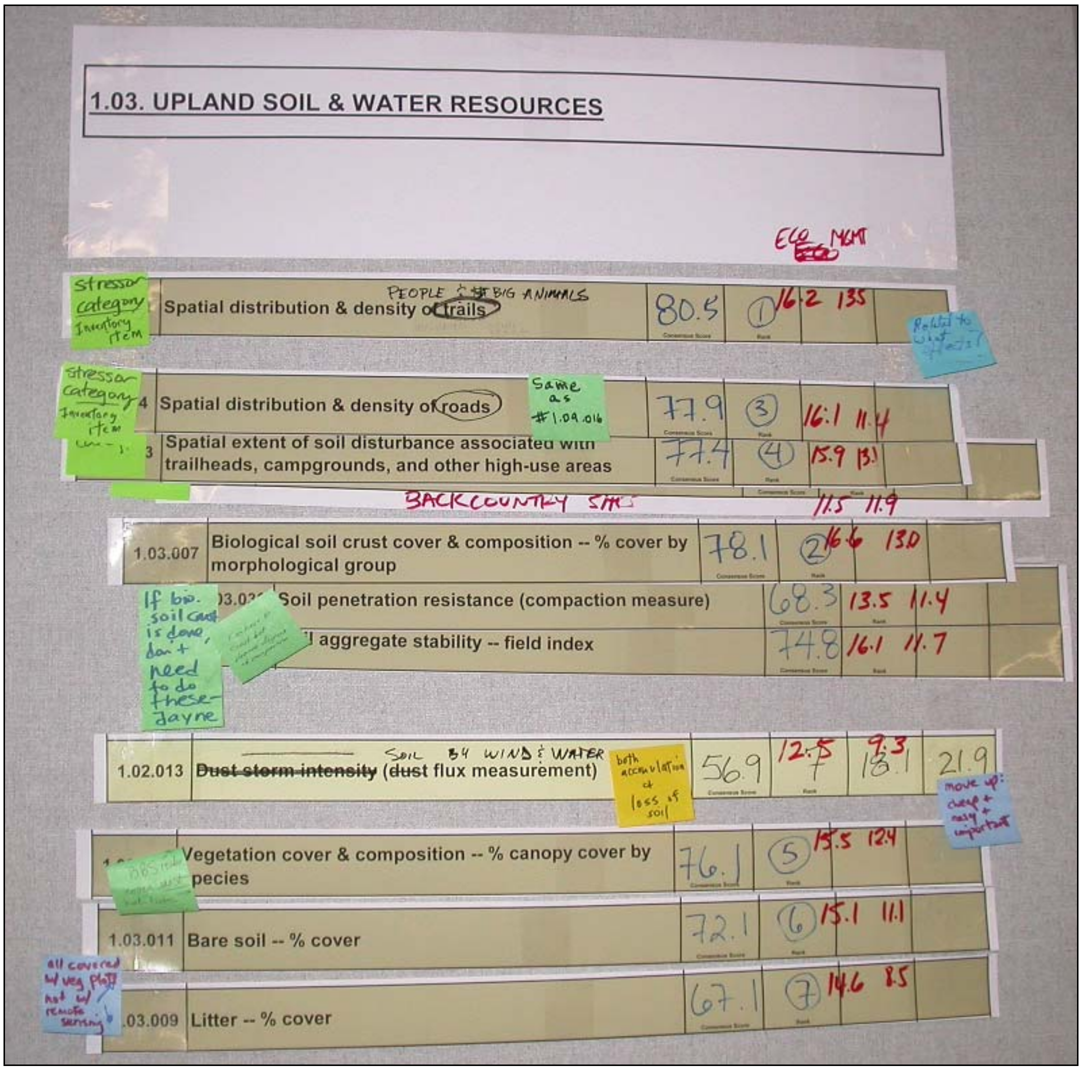

Figure 4. Candidate vital signs posted on meeting-room wall and annotated by participants in April 2003 NCPN vital-sign workshop.

Workshop Challenges and Issues

It is important to acknowledge several issues associated with vital-sign selection that arose during the workshop. Many of these are interrelated and are also associated with other aspects of the vital-sign evaluation process. These issues are identified briefly below, though an in-depth assessment of them is beyond the scope of this document.

- *The workshop process itself* – Throughout the workshop, but particularly during the early stages, several alternative approaches to vital-sign evaluation were suggested by participants. Most of these were linked in some way to issues described below. All of the suggested approaches had merit, but the group decided to proceed with the process as planned because of time constraints.

- *Specificity versus generality in the vital-sign concept* – Beginning with the Delphi process, the NCPN approached vital signs at a relatively detailed level. For example, in the first round of the Delphi survey, the NCPN solicited input from a broad scientific community regarding specific *measures* of key ecosystem processes or components. Thus many candidate vital signs considered during the second round of the Delphi process, the pre-workshop evaluation exercise, and the workshop itself were specific measures of structural or functional attributes of ecosystems (see Table 12). Many of the evaluation criteria found in scientific literature pertaining to ecological indicators are more appropriately applied to specific measures than to general ecosystem attributes (e.g., those criteria associated with response variability). This reinforced the detailed NCPN approach. Despite some advantages to the detailed approach, it greatly increased the complexity and overall magnitude of the vital-sign identification task. This was particularly evident during the workshop – when participants struggled to deal with the burden in an intense 2.5-day meeting. Subsequent to the workshop, NCPN staff synthesized workshop results and aggregated detailed vital signs to a more generalized level (see below).

- *Place and time specificity* – Related to the issue of vital-sign specificity, place-and-time specificity was an issue that repeatedly arose during the workshop. Usually this happened when comparing two or more measures that differed greatly in relative merit depending on the spatiotemporal context. Given the heterogeneity of management issues and biophysical environments among and within 16 NCPN units, it was impossible to deal with this level of detail in the workshop or preceding steps. Spatiotemporal specificity of monitoring questions and objectives will be a major focus during early stages of Phase III.

- *Cost considerations in relation to vital-sign evaluation and identification* – An on-going objective of the NCPN has been to frame a monitoring program that, in outline, identifies key park monitoring needs for purposes of maintaining and restoring the integrity of park ecosystems. NCPN from the outset has recognized that base funding associated with the vital-signs monitoring program will be insufficient to meet this comprehensive set of needs. Nevertheless, there is considerable value in scoping out a relatively comprehensive set of vital signs both for strategic purposes and for purposes of facilitating integrated whole-system thinking. This objective, as well as the associated NCPN vision that vital-signs monitoring ultimately will be accomplished through a variety of funding mechanisms and partnerships (and that some vital-signs may remain unfunded), was never made explicit during the workshop. Thus some workshop participants were frustrated by the fact that programmatic funding constraints played a relatively minor role in vital-sign evaluation discussions.

- *Vital signs as ecological indicators – or not?* – The official NPS definition of the vital-sign concept continues to evolve. Equating vital signs with the concept of *ecological indicators* (environmental attributes or measures that are particularly information-rich in the sense that they are somehow indicative of ecosystem integrity or condition), while at the same time recognizing that some vital-signs may be identified solely on the basis of human values, creates problems with communication and credibility among participants in the vital-sign identification process. Of course this side-steps the notion that ecological integrity is itself a concept derived from human values. Some participants in the NCPN workshop clearly differed in their perspectives on the proper scope of the vital-sign concept, and these differing perspectives contributed friction to an already-complex process.

- *The role and utility of ecological conceptual models* – The time and energy required from NCPN staff to manage the Delphi process and subsequent vital-sign evaluation exercises did not allow further development and refinement of ecological conceptual models presented in the Phase I report. Other than the Jenny-Chapin model adopted by the NCPN as a general model for ecosystem sustainability (Chapin et al. 1996; Evenden et al. 2002, Fig. 13, p. 78), conceptual models did not play an explicit role in the vital-sign evaluation process. However, because the Jenny-Chapin model was the basis for the organizational framework used throughout the vital-sign evaluation and selection process (Table 4), it strongly shaped the types of generalized environmental attributes and measures that were considered and ultimately identified by NCPN as vital signs. It is clear that more-detailed conceptual models will be required to inform site-specific monitoring design, including determination of the most appropriate measures of vital signs in particular spatiotemporal contexts (see Appendix H, Phase II report).

Post-Workshop Follow-Up and Synthesis

After the April 2003 workshop, the NCPN ecologist engaged in round of follow-up visits to parks. All NCPN parks were visited by network staff during May-June 2003 to identify park-specific monitoring needs and increase network familiarity with park resources and issues. Also during this period, network staff worked closely with the

Southern Colorado Plateau Network (SCPN) in developing unified conceptual-modeling approaches (see Appendix H, this Phase II report); vital-signs frameworks; and inventory, assessment and monitoring protocols for springs, seeps, and hanging gardens.

As indicated above, an outcome of the workshop was the evident need to aggregate attributes and measures considered during the vital-sign evaluation and selection process with the intent of identifying vital signs at a more-generalized level of detail. Park visits, coordination with the SCPN, and a reconsideration of input received during various phases of the vital-signs evaluation process facilitated the reorganization of candidate attributes and measures retained after the April workshop. These relatively specific measures were synthesized and aggregated by the NCPN ecologist into a shorter list of vital-sign candidates that is broadly applicable across the NCPN. This list was subsequently reviewed and accepted by park staff, and it served as the foundation for the development by NCPN and park staff of park-specific vital-sign tables presented in the body of the Phase II report. This list was retained with slight modification in the Phase III report. Potential measures associated with these vital signs are presented in Appendix O.

Table 11. Vital signs of broad applicability across the NCPN. List was derived from synthesis and aggregation of candidate measures retained following the April 2003 vital-signs workshop. See Appendix P for potential measures associated with individual vital signs.

Vital-Sign Category		**VITAL SIGN**
Ecosystem characteristics		
Climatic conditions		Precipitation patterns
		Air temperature patterns
		Wind patterns
Air quality		Atmospheric deposition
		Visibility
		Tropospheric ozone levels
Soil, water, and nutrient dynamics		Upland soil / site stability
		Upland hydrologic function
		Nutrient cycling
		Stream flow regime
		Stream / wetland hydrologic function
		Groundwater dynamics
Water quality		SEE WATER QUALITY TABLES
Disturbance regimes		Fire regimes
		Hillslope erosional processes
		Extreme climatic events
		Insect / disease outbreaks in forests and woodlands
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities (particular communities of interest may vary among parks in relation to values, threats, and probability/consequences of change.)
	At-risk species or communities	Status of at-risk species – amphibian populations
		Status of at-risk species – bat populations
		Status of at-risk species – Mexican spotted owl populations
		Status of at-risk species – peregrine falcon populations
		Status of at-risk species – other TES vertebrate populations (spp. vary by park)
		Status of at-risk species – TES plant populations (spp. vary by park)
		Status of at-risk communities – riparian-obligate birds
		Status of at-risk communities – sagebrush-obligate birds
		Status of at-risk communities – pinyon-juniper-obligate birds
		Status of at-risk communities – native fish communities
		Status of at-risk communities – native grassland / meadow plant communities
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities
	At-risk species or communities / Focal species or communities	Status of at-risk / focal communities – riparian / wetland plant communities
	Focal species or communities	Status of focal communities – biological soil crusts
		Status of focal communities – aquatic macroinvertebrates
		Status of focal communities – other aquatic communities (communities vary by park)
	Focal species or communities / Endemic species or unique communities	Status of focal / unique communities – spring, seep, & hanging-garden communities
	Endemic species or unique communities	Status of rare / endemic plant populations (spp. vary by park)
		Status of other unique communities (communities vary by park)
Landscape-level patterns		Land cover
		Land use
		Land condition
		Park insularization
		Landscape fragmentation and connectivity
Other vital-sign categories		
Stressors		Park use by visitors
		Invasive exotic plants

Table 11 cont.

Vital-Sign Category	VITAL SIGN
	Invasive, exotic, and/or feral animals
	Occurrence patterns of novel diseases / pathogens
Other vital-sign categories	
Stressors	Permitted consumptive / extractive activities on park lands
	Park administration and operations
	Changes in stream hydrologic regimes due to surface-water diversions
	Changes in stream hydrologic regimes due to large reservoirs
	Changes in groundwater hydrologic regimes due to groundwater extraction
	Adjacent / upstream land-use activities
	Non-compliant uses on park lands
Other natural resource values	Status of paleontological resources
	Status of natural night skies
	Status of natural soundscapes

Table 12. Master list of environmental attributes and measures considered as potential vital signs during the second round of the Delphi survey, the pre-workshop vital-sign evaluation survey, and the April 2003 vital sign workshop. Attributes and measures retained after the April 2003 workshop were aggregated by NCPN staff to develop endpoint-based vital signs.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
Ecosystem Structure & Function – CLIMATE					
1.01.001	Air temperature -- daily maximum & minimum	Drives or regulates multiple biotic & abiotic processes (can be used to derive daily freeze-thaw index)	X	X	X
1.01.002	Air temperature -- hourly average	Drives or regulates multiple biotic & abiotic processes	X		
1.01.003	Relative humidity -- hourly average	Drives or regulates multiple biotic & abiotic processes	X		
1.01.004	Precipitation -- amount per day	Drives or regulates multiple biotic & abiotic processes	X	X	X
1.01.005	Precipitation -- form (rain vs. snow)	Drives or regulates multiple biotic & abiotic processes	X	X	X
1.01.006	Precipitation events -- frequency, magnitude, and duration	Drives or regulates multiple biotic & abiotic processes, including erosion of soils and fossiliferous geologic strata	X	X	X
1.01.007	Soil temperature -- daily maximum & minimum	Drives or regulates multiple biotic & abiotic processes (can be used to derive daily freeze-thaw index)	X		
1.01.008	Soil temperature -- hourly average	Drives or regulates multiple biotic & abiotic processes	X		
1.01.009	Soil moisture -- hourly average	Drives or regulates multiple biotic & abiotic processes	X		
1.01.010	Wind velocity -- hourly average & peak gust	Drives or regulates multiple biotic & abiotic processes, including erosion of soils and fossiliferous geologic strata	X		
1.01.011	Wind direction -- hourly average	Directional component to resource redistribution	X		
1.01.012	Wind events -- frequency, magnitude, and duration	Drives or regulates multiple biotic & abiotic processes, including erosion of soils and fossiliferous geologic strata	X	X	X
1.01.013	UV radiation -- hourly average	Stressor affecting physiological processes	X		
1.01.014	Photosynthetically active radiation (PAR) -- hourly average	Required for photosynthetic activity	X		
1.01.015	Plant phenology (date of "green-up," flowering, or other life-history events)	Integrated indicator of climatic conditions	X	X	

Table 12 cont.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
Ecosystem Structure & Function – AIR QUALITY					
1.02.001	Nitrogen compounds -- atmospheric deposition	Nutrient enrichment, acidification	X	X	X
1.02.002	Sulfur compounds -- atmospheric deposition	Nutrient enrichment, acidification	X	X	X
1.02.003	Sulfur dioxide -- atmospheric concentration	Physiological stressor	X		
1.02.004	Major cations & anions -- atmospheric deposition	Mineral inputs	X	X	X
1.02.005	Air toxics (organics, pesticides, metals, radionucleides) -- atmospheric deposition	Contaminants	X		
1.02.006	Air toxics -- atmospheric concentrations	Contaminants	X		
1.02.007	Ozone -- atmospheric concentrations	Physiological stressor	X	X	X
1.02.008	Particulates -- atmospheric concentrations	Visibility impacts	X	X	X
1.02.009	Visibility -- visual range	Air-quality related resource value	X	X	X
1.02.010	Visibility -- light extinction	Air-quality related resource value	X	X	X
1.02.011	Visibility -- deciview	Air-quality related resource value	X	X	X
Ecosystem Structure & Function – AIR QUALITY					
1.02.012	Dust storm frequency & duration	Soil redistribution, potential nutrient enrichment, visibility impairment	X	X	
1.02.013	Dust storm intensity (dust flux measurement)	Soil redistribution, potential nutrient enrichment, visibility impairment	X	X	
1.02.014	Ozone-sensitive plants -- foliar injury, physiological performance	Stress response	X	X	X
1.02.015	Lichens -- tissue chemistry	Bioaccumulation	X		
1.02.016	Lichens -- physiological performance	Stress response			
1.02.017	Surface water chemistry (pH, nutrient & toxin concentrations, acid neutralizing capacity)	Effects of atmospheric deposition		X	
1.02.018	Precipitation pH	Indicates acid inputs			
Ecosystem Structure & Function – UPLAND SOIL & WATER RESOURCES					
1.03.001	Spatial distribution & density of trails	Erosion susceptibility, soil biotic activity, nutrient cycling, soil water-holding capacity, watershed hydrologic function	X	X	X
1.03.002	Spatial distribution, abundance & extent of road-side pullouts	Erosion susceptibility, soil biotic activity, nutrient cycling, soil water-holding capacity, watershed hydrologic function	X		
1.03.003	Spatial extent of soil disturbance associated with trailheads, campgrounds, and other high-use areas	Erosion susceptibility, soil biotic activity, nutrient cycling, soil water-holding capacity, watershed hydrologic function	X	X	X
1.03.004	Spatial distribution & density of roads	Watershed hydrologic function, erosion susceptibility	X	X	X
1.03.005	Spatial extent and degree of deflation terrain	Aeolian soil movement & erosion	X		
1.03.006	Soil aggregate stability -- field index	Soil stability, soil biotic activity, infiltration capacity, soil organic matter content	X	X	X
1.03.007	Biological soil crust cover & composition -- % cover by morphological group	Soil stability, soil biotic activity, nutrient cycling	X	X	X
1.03.008	Biological soil crust biomass	Soil stability, soil biotic activity, nutrient cycling	X		
1.03.009	Litter -- % cover	Soil stability, organic matter inputs	X	X	X

Table 12 cont.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
1.03.010	Rock -- % cover	Soil stability	X		
1.03.011	Bare soil -- % cover	Erosion susceptibility	X	X	X
1.03.012	Downslope fetch-length of unvegetated patches	Erosion susceptibility	X		
1.03.013	Vegetation cover & composition -- % canopy cover by species	Rainfall interception, soil surface protection, wind obstruction, organic matter inputs	X	X	X
1.03.014	Vegetation cover & composition -- % basal cover by species	Overland flow obstruction, soil & water retention, infiltration capacity	X		
1.03.015	Vegetation structure -- canopy height	Wind obstruction	X		
1.03.016	Vegetation -- ratio of long-lived grasses to short-lived grasses	Resistance to drought & other disturbances, erosion susceptibility	X		
1.03.017	Vegetation -- seed production	Regeneration potential, indicates resilience to drought & other disturbances, erosion susceptibility	X		
1.03.018	Soil surface roughness	Overland flow obstruction, soil & water retention, infiltration capacity	X		
Ecosystem Structure & Function – UPLAND SOIL & WATER RESOURCES					
1.03.019	Soil organic matter content	Soil biotic activity, nutrient cycling, soil stability, infiltration capacity	X		
1.03.020	Soil color	Soil organic matter content, soil biotic activity, degree of biological soil crust development	X		
1.03.021	Soil CO_2 flux after rewetting	Soil biotic activity	X		
1.03.022	Root biomass	Soil biotic activity, soil-holding capacity	X		
1.03.023	Decomposition rate	Soil biotic activity, nutrient cycling	X		
1.03.024	Total soil carbon & nitrogen pools	Soil biotic activity, nutrient cycling	X		
1.03.025	Soil respiration rate	Soil biotic activity, nutrient cycling	X		
1.03.026	Soil nitrogen mineralization rate	Soil biotic activity, nutrient cycling	X		
1.03.027	Soil nitrogen isotope ratios	Soil biotic activity, nutrient cycling	X		
1.03.028	Soil food web composition, structure, & dynamics	Soil biotic activity, nutrient cycling	X		
1.03.029	Soil bulk density (compaction measure)	Infiltration capacity, soil water-holding capacity, soil biotic activity, nutrient cycling	X		
1.03.030	Soil penetration resistance (compaction measure)	Infiltration capacity, soil water-holding capacity, soil biotic activity, nutrient cycling	X	X	X
1.03.031	Infiltration rate	Water retention, erosion susceptibility, soil water-holding capacity, soil biotic activity, nutrient cycling	X		
1.03.032	Spatial variability in soil-quality attributes (e.g., sub-canopy values vs. interspace values)	Indicates change in spatial distribution of soil resources	X		
1.03.033	Changes in soil-surface height from benchmark	Soil erosion & deposition	X		X
1.03.034	Distribution & abundance of natural sediment traps (e.g., woody debris)	Watershed capacity for soil & water retention	X		
1.03.035	Soil movement / accumulation due to fluvial processes (e.g., deposition behind silt fences or natural sediment traps)	Watershed hydrologic function, runoff & erosion	X		X
1.03.036	Arroyo channel cross sections	Watershed hydrologic function, runoff & erosion	X		
1.03.037	Flow frequency of ephemeral streams in relation to	Watershed hydrologic function, runoff & erosion	X		

Table 12 cont.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
	precipitation events in well-defined watersheds				
1.03.038	Discharge of small streams in relation to precipitation events in well-defined watersheds	Watershed hydrologic function, runoff & erosion	X		
1.03.039	Sediment loads in small streams in relation to precipitation events in well-defined watersheds	Watershed hydrologic function, runoff & erosion	X		
1.03.040	Nutrient concentrations in small streams in relation to precipitation events in well-defined watersheds	Watershed hydrologic function, runoff & erosion	X		
1.03.041	Slope movement	Mass wasting, watershed stability	X		
1.03.042	Number, distribution, and condition / spatial extent of backcountry campsites	Erosion susceptibility, soil biotic activity, nutrient cycling, soil water-holding capacity, watershed hydrologic function.		X	X
1.03.043	Soil movement / accumulation due to aeolian processes -- dust traps				X
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
Ecosystem Structure & Function – UPLAND DISTURBANCE REGIMES					
1.04.001	Fine surface fuels -- distribution, cover and spatial continuity	Fuel accumulation, indicates potential for carrying surface fire	X	X	X
1.04.002	Fine surface fuels -- ratio of exotic cover to native cover	Relative contribution of exotic plants to fine-fuel accumulation	X	X	X
1.04.003	Ladder fuels -- distribution & abundance	Fuel accumulation, indicates potential for canopy fires	X		
1.04.004	Fuel types -- distribution & abundance	Fuel accumulation, indicates potential occurrence & characteristics of fire	X		
1.04.005	Fire occurrence on park lands -- frequency, spatial patterning, intensity, and timing	Directly reflects fire regime, drives change in multiple ecosystem properties & functions, affects landscape-level patch structure & diversity	X	X	X
1.04.006	Fire occurrence on adjacent lands -- frequency, spatial patterning, intensity, and timing	Potential impacts on within-park fire regimes	X	X	
1.04.007	Proportions of park lands in different "fire regime current-condition classes"	Depicts degree of departure from historical fire regime within park	X	X	X
1.04.008	Proportions of adjacent lands in different "fire regime current-condition classes"	Potential impacts on within-park fire regimes	X		
1.04.009	Spatial distribution of fire regime current-condition classes on park lands (a map)	Facilitates assessment & communication of fire-regime conditions	X	X	X
1.04.010	Spatial distribution of fire regime current-condition classes on adjacent lands (a map)	Facilitates assessment & communication of external fire-regime conditions that may impact park resources	X	X	
1.04.011	Fire management / suppression activities on park lands	Direct management impacts on within-park fire regimes	X	X	X
1.04.012	Fire management / suppression activities on	Potential impacts on within-park fire regimes	X		

Table 12 cont.

ID	Candidate attributes / measures	Associated processes / functions, or other rationale	In Delphi 2 survey	In pre-workshop survey & workshop	Retained after workshop
Vital-Sign Category					
	adjacent lands				
1.04.013	Vegetation -- distribution & abundance of diseased or insect-infested trees in woodland / forest ecosystems	Insect disturbance, fire potential	X		X
1.04.014	Vegetation -- ratio of insect-infected to uninfected trees in woodland / forest ecosystems	Insect disturbance, fire potential	X		X
1.04.015	Vegetation -- distribution & abundance of drought-killed trees in woodland / forest ecosystems	Drought disturbance, fire potential			X
Ecosystem Structure & Function – UPLAND & RIPARIAN COMMUNITIES					
1.05.001	Soil food web composition, structure, & dynamics	Biodiversity component, multiple ecosystem functions	X		
1.05.002	Biological soil crust cover & composition -- % cover by morphological group	Biodiversity component, invasion susceptibility (mediates plant establishment), habitat structure / stability, multiple ecosystem functions	X	X	X
1.05.003	Vegetation cover & composition -- % canopy cover by species	Biodiversity component, habitat structure, multiple ecosystem functions	X	X	X
1.05.004	Vegetation composition -- frequency by species	Biodiversity component, habitat structure, other ecosystem functions	X	X	
1.05.005	Vegetation structure -- canopy height by stratum	Habitat structure	X		
1.05.006	Vegetation structure -- canopy volume by stratum	Habitat structure	X		
1.05.007	Vegetation structure -- size-class structure of riparian shrubs & trees	Community / population dynamics, effects of herbivory, habitat structure	X		
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
Ecosystem Structure & Function – UPLAND & RIPARIAN COMMUNITIES					
1.05.008	Vegetation structure -- stem density of riparian shrubs & trees	Community / population dynamics, effects of herbivory, habitat structure	X		
1.05.009	Vegetation structure -- age- or size-class structure of key upland shrubs & trees	Community / population dynamics, habitat structure	X		
1.05.010	Vegetation structure -- stem density of key upland shrubs & trees	Community / population dynamics, habitat structure	X		
1.05.011	Vegetation -- frequency of seed production of key forage species	Regeneration potential; effects of herbivory; resilience to drought, herbivory & other disturbances	X		
1.05.012	Vegetation -- ratio of unpalatable to palatable canopy cover	Effects of herbivory on ecosystem / community structure	X		
1.05.013	Vegetation -- annual above-ground production consumed by herbivores	Effects of herbivory on ecosystem function	X		
1.05.014	Vegetation -- abundance of diseased or insect-infested trees	Community / population dynamics, habitat structure / quality	X		
1.05.015	Vegetation -- ratio of exotic to native canopy cover	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	

Table 12 cont.

ID	Candidate attributes / measures	Associated processes / functions, or other rationale	In Delphi 2 survey	In pre-workshop survey & workshop	Retained after workshop
Vital-Sign Category					
1.05.016	Invasive exotic plants -- % canopy cover by species	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X
1.05.017	Invasive exotic plants -- spatial distribution by species	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X
1.05.018	Invasive exotic plants -- frequency by species	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X		
1.05.019	Invasive exotic plants -- age- or size-class structure of long-lived woody invaders	Competition with native species, population / community dynamics, habitat quality, potential alteration of ecosystem structure & function	X		
1.05.020	Standing dead trees in forested ecosystems -- abundance	Habitat structure	X		
1.05.021	Downed woody debris in forested ecosystems -- abundance	Habitat structure	X		
1.05.022	Keystone species -- abundance	Biodiversity component, ecosystem functions	X		
1.05.023	Invasive birds -- abundance of brown-headed cowbirds	Competition with native species, habitat quality	X		
1.05.024	Avian pinyon-juniper obligates -- abundance & diversity	Biodiversity component, integration with regional conservation & monitoring programs	X		X
1.05.025	Avian sagebrush obligates -- abundance & diversity	Biodiversity component, integration with regional conservation & monitoring programs	X		X
1.05.026	Avian riparian obligates -- abundance & diversity	Biodiversity component, integration with regional conservation & monitoring programs	X	X	X
1.05.027	Avian aspen-forest obligates -- abundance & diversity	Biodiversity component, integration with regional conservation & monitoring programs	X		
1.05.028	Resident avifauna -- abundance & diversity	Biodiversity component, prey base, integration with regional conservation & monitoring programs	X		
1.05.029	Avian predators -- abundance & diversity	Biodiversity component, predation, integration with regional conservation & monitoring programs	X		
1.05.030	Standing stock faunal biomass	Prey base	X		
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
Ecosystem Structure & Function – UPLAND & RIPARIAN COMMUNITIES					
1.05.031	Small mammals -- abundance & diversity	Biodiversity component, prey base, granivory, herbivory	X		
1.05.032	Native ungulates -- abundance & diversity	Biodiversity component, herbivory, prey base	X		
1.05.033	Mammalian predators -- abundance & diversity	Biodiversity component, predation	X		
1.05.034	Bats -- abundance & diversity	Biodiversity component, integration with regional conservation & monitoring programs	X		X
1.05.035	Reptiles -- abundance & diversity	Biodiversity component, prey base	X		
1.05.036	Invertebrates -- abundance & diversity	Biodiversity component, prey base, other ecosystem functions	X		

Table 12 cont.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
1.05.037	Invertebrate pollinators -- abundance & diversity	Biodiversity component, pollination services, prey base	X		
1.05.038	Invertebrate herbivores -- abundance & diversity	Biodiversity component, herbivory, prey base	X		
1.05.039	Soil invertebrates -- abundance & diversity				
1.05.040	Fossorial vertebrates -- abundance & diversity				
1.05.041	Spring / seep / hanging-garden obligates -- abundance & diversity				X
Ecosystem Structure & Function – AQUATIC, RIPARIAN & WETLAND HYDROLOGIC / GEOMORPHIC REGIMES					
1.06.001	Stream flow regime -- continuous flow / discharge variables described by magnitude, frequency, timing, duration, and rate of change	Direct measure of hydrologic regime, major driver of aquatic & riparian ecosystem processes & properties, determinant of channel structure / physical habitat, susceptibility to invasion by exotic species	X	X	X
1.06.002	Degree of departure of current hydrologic regime from historic hydrologic regime, compared on basis of flow variables	Indicates current hydrologic condition in relation to historic	X	X	
1.06.003	Stream stage (gage height) -- continuous measure	Surrogate measure for hydrologic regime	X	X	
1.06.004	Degree of departure of current river-backwater extent from historic	Indicates degree of backwater habitat loss / alteration	X		
1.06.005	Number & duration of dry periods in streams & rivers	Impacts on multiple aquatic & riparian ecosystem processes & properties	X	X	X
1.06.006	Distribution & abundance of beaver dams	Sediment & water retention, physical habitat structure, floodplain formation & maintenance,	X	X	
1.06.007	Channel morphology -- surveyed cross sections (for width:depth ratio & entrenchment ratio)	Energy dissipation, sediment & water retention, physical habitat structure, floodplain formation & maintenance, upland hillslope processes	X	X	X
1.06.008	Channel morphology -- width	Energy dissipation, sediment & water retention, physical habitat structure, floodplain formation & maintenance, upland hillslope processes	X		
1.06.009	Channel morphology -- sinuosity	Energy dissipation, sediment & water retention, physical habitat structure, floodplain formation & maintenance, upland hillslope processes	X		
1.06.010	Channel morphology -- surveyed longitudinal profile / gradient	Sediment transport, habitat structure, channel adjustment	X		
1.06.011	Stream sediment load / transport	Sediment transport, upland hillslope processes, channel adjustment	X		X
1.06.012	Substrate pebble counts	Sediment transport, habitat structure, upland hillslope processes, channel adjustment	X		
Ecosystem Structure & Function – AQUATIC, RIPARIAN & WETLAND HYDROLOGIC / GEOMORPHIC REGIMES					
1.06.013	Substrate particle-size distribution	Sediment transport, habitat structure, upland hillslope processes, channel adjustment	X		
1.06.014	Large woody debris -- distribution & abundance	Sediment & water retention, energy dissipation, floodplain development, bank stabilization, channel	X		

Table 12 cont.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
		maintenance, energy & nutrient inputs			
1.06.015	Vegetation cover -- % canopy cover by species, longitudinal along streambank	Bank stabilization, sediment retention, channel maintenance, energy & nutrient inputs	X	X	X
1.06.016	Vegetation cover -- % canopy cover by species, cross-sectional across riparian zones & wetlands	Sediment & water retention, energy dissipation, floodplain development, ground-water recharge, channel maintenance, energy & nutrient inputs; indicator of hydrologic regime	X	X	X
1.06.017	Vegetation structure -- size-class structure of riparian shrubs & trees	Recruitment, maintenance / persistence of hydrologic function	X		
1.06.018	Vegetation vigor -- live canopy volume of native riparian trees	Indicator of altered hydrologic regime (floodplain water-table level)	X		
1.06.019	Vegetation -- % cover of tamarisk	Indicator of altered hydrologic regime; competition with native species	X	X	X
1.06.020	Vegetation -- areal extent of wetland vegetation	Indicator of hydrologic regime	X	X	X
1.06.021	Riparian & wetland water-table level in relation to ground-surface elevations	Hydrologic regime, effects of diversions / withdrawals, impacts to wetland / riparian vegetation	X	X	X
1.06.022	Water quantity (flow / discharge) at seeps & springs	Indicator of hydrologic regime	X	X	X
1.06.023	Hanging gardens -- areal extent of wet soil / substrate	Surrogate for flow from seep zones, indicator of hydrologic regime	X		
1.06.024	Stage / level or depth of standing surface water in ponds / rock pools	Indicator of hydrologic regime, water retention	X		
1.06.025	Soil bulk density (compaction measure) in wet / mesic meadows	Infiltration capacity, water retention, ground-water recharge, effects of trampling	X		
1.06.026	Soil penetration resistance (compaction measure) in wet / mesic meadows	Infiltration capacity, water retention, ground-water recharge, effects of trampling	X		
1.06.027	Density of roads & trails within riparian & wetland buffer zones	Sedimentation, hydrologic function	X	X	X
1.06.028	Spatial distribution & abundance of road & trail crossings across riparian & wetland zones	Bank stability, sedimentation, channel morphology, hydrologic function, habitat structure	X	X	X
1.06.029	Groundwater depth in wells pertinent to park groundwater recharge	Hydrologic regime, effects of diversions / withdrawals, impacts to springs / seeps / hanging gardens	X	X	X
1.06.030	Spatial distribution & size of sandy beaches along major rivers				X
Ecosystem Structure & Function – WATER QUALITY					
1.07.001	Temperature	NPS core parameter, impacts multiple ecosystem / physiological processes	X	X	X
1.07.002	pH	NPS core parameter, impacts multiple ecosystem / physiological processes	X	X	X
Ecosystem Structure & Function – WATER QUALITY					
1.07.003	Dissolved oxygen	NPS core parameter, impacts multiple ecosystem / physiological processes	X	X	X
1.07.004	Specific conductance	NPS core parameter, impacts multiple ecosystem /	X	X	X

Table 12 cont.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
		physiological processes			
1.07.005	Flow / discharge (flowing-water body) at time of sample	NPS core parameter, required for interpretation and/or calculation of other parameters	X	X	X
1.07.006	Stage / level (non-flowing water body) at time of sample	NPS core parameter, required for interpretation and/or calculation of other parameters	X	X	X
1.07.007	Common cations & anions	Concentrations affect physiological processes	X		
1.07.008	Alkalinity / acid neutralizing capacity (ANC)	Indicates capacity of water to buffer acidic inputs or processes	X	X	
1.07.009	Total dissolved solids (TDS)	Concentrations affect physiological processes	X		
1.07.010	Total suspended solids (TSS)	Light penetration (water clarity), siltation	X		
1.07.011	Turbidity	Light penetration (water clarity), siltation	X		
1.07.012	Transmissivity	Light penetration (water clarity), siltation	X		
1.07.013	Secchi disk depth	Light penetration (water clarity), siltation	X		
1.07.014	Chlorophyll a	Surrogate indicator of phytoplankton biomass	X		
1.07.015	Biological oxygen demand (BOD)	Indicates levels of organic materials in water	X		
1.07.016	Dissolved organic carbon (DON)	Energy source	X		
1.07.017	Suspended organic carbon (SOC)	Energy source	X		
1.07.018	Nutrients -- nitrogen compounds	Nutrient source, potential system stressor due to enrichment	X	X	
1.07.019	Nutrients -- phosphorus compounds	Nutrient source, potential system stressor due to enrichment	X	X	
1.07.020	Pathogens -- fecal coliforms, periodic sampling	Biological stressor / pollutant	X		
1.07.021	Pathogens -- giardia	Biological stressor / pollutant	X		
1.07.022	Toxics -- metals	Chemical stressor / pollutant	X		
1.07.023	Toxics -- organic compounds	Chemical stressor / pollutant	X		
1.07.024	Radiological contaminants	Radiological stressor / pollutant	X		
1.07.025	Aquatic macroinvertebrates -- abundance & diversity	Integrated indicator of water-quality conditions, food-web component	X	X	
1.07.026	Periphyton -- biomass & diversity	Integrated indicator of water-quality conditions, primary producers, food-web component	X		
1.07.027	Fish -- tissue concentrations of contaminants	Bioaccumulation	X		
Ecosystem Structure & Function – AQUATIC COMMUNITIES					
1.08.001	Periphyton -- biomass & diversity	Biodiversity component, primary producers	X		
1.08.002	Phytoplankton -- biomass & diversity	Biodiversity component, primary producers	X		
1.08.003	Macrophytic aquatic plants -- abundance & diversity	Biodiversity component, primary producers	X		
1.08.004	Macrophytic aquatic plants -- ratio of exotic abundance to native abundance	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X		
1.08.005	Exotic aquatic plants -- abundance & distribution	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**

Table 12 cont.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
Ecosystem Structure & Function – AQUATIC COMMUNITIES					
1.08.006	Aquatic macroinvertebrates -- abundance & diversity	Biodiversity component, food-chain component, multiple ecosystem functions, integration with regional conservation & monitoring programs	X	X	X
1.08.007	Aquatic macroinvertebrates -- ratio of exotic abundance to native abundance	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X		
1.08.008	Exotic aquatic macroinvertebrates (e.g., crayfish) -- abundance & distribution	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X
1.08.009	Amphibians -- abundance & diversity	Biodiversity component, food-chain component, integration with regional conservation & monitoring programs	X	X	X
1.08.010	Amphibians -- ratio of exotic abundance to native abundance	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X		
1.08.011	Exotic amphibians (e.g., bullfrogs) -- abundance & distribution	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X
1.08.012	Fish -- abundance & diversity	Biodiversity component, food-chain component, integration with regional conservation & monitoring programs	X	X	X
1.08.013	Fish -- ratio of exotic abundance to native abundance	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X
1.08.014	Exotic fish -- abundance & distribution	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X
1.08.015	Keystone species -- river otters -- abundance & distribution	Biodiversity component, key predator	X		
1.08.016	Keystone species -- beavers -- abundance & distribution	Biodiversity component, key ecosystem / hydrologic engineer, habitat alteration	X	X	
1.08.017	Native aquatic community composition -- degree of departure from historic on basis of compositional similarity	Indicates degree of biotic alteration from historic	X		
1.08.018	Native aquatic community "biotic integrity" -- degree of departure from reference condition on basis of multimetric index	Indicates degree of departure from desired reference condition	X		
1.08.019	Compositional similarity of native aquatic communities in the Green and Yampa Rivers	Indicates degree of departure from natural conditions imposed by Flaming Gorge Dam on Green River	X		
1.08.020	Periphyton community composition -- degree of departure from reference-site benchmark	Indicates degree of departure from desired reference condition			
Ecosystem Structure & Function – LANDSCAPE-LEVEL PATTERNS					
1.09.001	Movement / habitat-use patterns of medium-to-large carnivores on park and adjacent lands	Landscape connectivity, linkages between parks & adjacent lands	X		
1.09.002	Movement / habitat-use patterns of large ungulates on park and adjacent lands	Landscape connectivity, linkages between parks & adjacent lands	X	X	X
1.09.003	Movement / habitat-use patterns of wide-ranging avian predators on park and adjacent lands	Landscape connectivity, linkages between parks & adjacent lands	X		

Table 12 cont.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
1.09.004	Compositional similarity of key taxonomic groups among key landscape components or ecosystem types	Landscale-level taxonomic diversity ("beta diversity"), potential indicator of compositional homogenization due to invasive spp. or other factors	X		
TEcosystem Structure & Function – LANDSCAPE-LEVEL PATTERNS					
1.09.005	Proportions of park lands categorized by different land-use & land-cover / ecosystem types	Land-use / land-cover trends, landscape-level patch heterogeneity & habitat structure, effects on watershed hydrologic function & water quality	X	X	X
1.09.006	Proportions of adjacent lands categorized by different land-use & land-cover / ecosystem types	Land-use / land-cover trends, landscape-level patch heterogeneity & habitat structure, effects on watershed hydrologic function & water quality	X	X	X
1.09.007	Patch-size distribution of different land-cover / ecosystem types on park lands (a histogram)	Landscape patchiness, fragmentation, invasion susceptibility, microclimatic alteration & other edge effects	X	X	X
1.09.008	Patch-size distribution of different land-cover / ecosystem types on adjacent lands (a histogram)	Landscape patchiness, fragmentation, invasion susceptibility, microclimatic alteration & other edge effects	X		
1.09.009	Spatial distribution of land-cover / ecosystem patches on park lands (a map)	Facilitates assessment & communication of landscape-level patch heterogeneity & habitat structure, patch demography, connectivity	X	X	X
1.09.010	Spatial distribution of land-cover / ecosystem patches on adjacent lands (a map)	Facilitates assessment & communication of landscape-level patch heterogeneity & habitat structure, connectivity, patch demography, potential impacts on park resources	X	X	X
1.09.011	Proportions of park lands in different ecosystem-condition classes defined by degree of departure from desired condition	Aggregate indicator of park ecological condition	X	X	X
1.09.012	Proportions of adjacent lands in different ecosystem-condition classes defined by degree of departure from desired condition	Aggregate indicator of adjacent ecological conditions, potential impacts on park resources	X		X
1.09.013	Spatial distribution of land-cover / ecosystem patches on park lands, classified by ecosystem condition (a map)	Facilitates assessment & communication of landscape-level resource conditions	X	X	X
1.09.014	Spatial distribution of land-cover / ecosystem patches on adjacent lands, classified by ecosystem condition (a map)	Facilitates assessment & communication of landscape-level resource conditions, potential impacts on park resources	X		X
1.09.015	Cross-boundary contrast between park lands and adjacent lands on basis of land use, land cover, and/or ecosystem condition	Park insularization, edge contrast, invasion susceptibility, multiple impacts on within-park ecosystems & populations	X	X	X
1.09.016	Spatial distribution & density of roads on adjacent lands	Watershed hydrologic function & water quality, invasion susceptibility, other potential impacts to park resources	X	X	X
1.09.017	Movement / habitat-use patterns of mountain lions on park and adjacent lands				X

Table 12 cont.

ID	Candidate attributes / <u>measures</u>	Associated processes / functions, or other rationale	In Delphi 2 survey	In pre-workshop survey & workshop	Retained after workshop
Vital-Sign Category					
Species / Populations of Concern					
2.01.001	Plants -- Arizona willow (*Salix arizonica*)	Federally protected species	X	X	
2.01.002	Plants -- Despain's cactus (*Pediocactus despaini*)	Federally endangered species	X	X	
2.01.003	Plants -- Jone's cycladenia (*Cycladenia humulis var. jonesii*)	Federally threatened species	X	X	
2.01.004	Plants -- Last Chance townsendia (*Townsendia aprica*)	Federally threatened species	X	X	
2.01.005	Plants -- Maguire daisy (*Erigeron maguirei*)	Federally threatened species	X	X	
2.01.006	Plants -- Shivwits Milkvetch (*Astragalus eremiticus var. ampullarioides*)	Federally endangered species	X	X	
2.01.007	Plants -- Sye's Butte plainsmustard (*Schoenocrambe barnebyi*)	Federally endangered species	X	X	
2.01.008	Plants -- Ute ladies' tresses (*Spiranthes diluvialis*)	Federally threatened species	X	X	
2.01.009	Plants -- Winkler's pin-cushion cactus (*Pediocactus winkleri*)	Federally threatened species	X	X	
2.01.010	Plants -- Wonderland Alice-flower (*Gilia caespitosa*)	Candidate for federal listing	X	X	
2.01.011	Plants -- Wright fishhook cactus (*Sclerocactus wrightiae*)	Federally endangered species	X	X	
2.01.012	Plants -- Hanging-garden endemic species	Valued endemic taxa	X	X	
2.01.013	Plants -- Other rare and/or endemic species	Valued rare and/or endemic taxa	X	X	
2.01.014	Invertebrates -- Zion snail (*Physa zionis*)	Valued endemic taxon	X	X	
2.01.015	Fish -- Bonytail chub (*Gila elegans*)	Federally endangered species	X	X	
2.01.016	Fish -- Colorado pikeminnow (*Ptychocheilus lucius*)	Federally endangered species	X	X	
2.01.017	Fish -- Humpback chub (*Gila cypha*)	Federally endangered species	X	X	
2.01.018	Fish -- Razorback sucker (*Xyrauchen texanus*)	Federally endangered species	X	X	
2.01.019	Fish -- Virgin spinedace (*Lepidomeda mollispinis*)	Federally protected species	X	X	
2.01.020	Reptiles -- Desert tortoise (*Gopherus agassazii*)	Federally threatened species	X	X	
2.01.021	Amphibian populations -- proportion of area occupied (PAO)	Valued sensitive taxa, potentially declining; focus of nationwide Amphibian Research & Monitoring Initiative which uses PAO measure	X	X	X
2.01.022	Amphibian populations -- frequency of malformations	Valued sensitive taxa, with reported frequencies of deformities that may exceed natural levels	X	X	X
2.01.023	Birds -- American peregrine falcon (*Falco peregrinus anatum*)	Valued species of interest	X	X	X
2.01.024	Birds -- Bald eagle (*Haliaeetus leucocephalus*)	Federally threatened species	X	X	
2.01.025	Birds -- California condor (*Gymnogyps californianus*)	Federally protected species	X	X	
2.01.026	Birds -- Gunnison sage grouse (*Centrocercus minimus*)	Candidate for federal listing	X	X	
2.01.027	Birds -- Mexican spotted owl (*Strix occidentalis lucida*)	Federally threatened species	X	X	X
2.01.028	Birds -- Southwestern willow flycatcher (*Empidonax trailli extimus*)	Federally endangered species	X	X	
2.01.029	Birds -- Yellow-billed cuckoo (*Coccyzus americanus*)	Candidate for federal listing	X	X	

Table 12 cont.

ID	Candidate attributes / measures	Associated processes / functions, or other rationale	In Delphi 2 survey	In pre-workshop survey & workshop	Retained after workshop
Vital-Sign Category					
2.01.030	Birds -- Gray vireo (*Viero vicinior*) -- density & productivity	Priority species identified by Utah Partners in Flight, assoc. with pinyon-juniper ecosystems	X	X	
2.01.031	Birds -- Black-throated gray warbler (*Dendroica nigrescens*) -- density & productivity	Priority species identified by Utah Partners in Flight, assoc. with pinyon-juniper ecosystems	X	X	
2.01.032	Birds -- Lucy's warbler (*Vermivora luciae*) -- density & productivity	Priority species identified by Utah Partners in Flight, assoc. with riparian ecosystems	X	X	
2.01.033	Birds -- Lewis woodpecker (*Melanerpes lewis*) -- density & productivity	Priority species identified by Utah Partners in Flight, assoc. with riparian ecosystems	X	X	
2.01.034	Birds -- Golden eagle (*Aquila chrysaetos*)	Valued species of interest	X	X	
2.01.035	Birds -- Western burrowing owl (*Athene cunicularia hypugia*)	Valued species of interest	X	X	
2.01.036	Birds -- Northern goshawk (*Accipiter gentilis*)	Valued species of interest	X	X	
2.01.037	Mammals -- Utah prairie dog (*Cynomys parvidens*)	Federally threatened species	X	X	
2.01.038	Mammals -- Gunnison prairie dog (*Cynomys gunnisoni*)	Valued species of concern	X	X	
Species / Populations of Concern					
2.01.039	Mammals -- Mountain lions (*Felis concolor*)	Valued species of interest	X	X	
2.01.040	Mammals -- Desert bighorn sheep (*Ovis canadensis nelsoni*)	Valued species of interest	X	X	
2.01.041	Invertebrates -- Other particular species				
Other Natural Resource Values					
3.01.001	Frequency of occurrence & spatial distribution of debris flows in major-river corridors	River-navigation hazards	X		
3.01.002	Spatial distribution & size of sandy beaches along major rivers	Campsite availability	X	X	
3.01.003	Sound levels (in dB) by frequency	Sound intensity, anthropogenic impacts to natural soundscape	X	X	X
3.01.004	Sound sources (recorded audibility data)	Sound identity / source, anthropogenic impacts to natural soundscape	X	X	X
3.01.005	Night sky brightness	Impacts of light pollution on natural night skies	X	X	X
3.01.006	Vegetation -- % canopy cover by species on fossil-bearing substrates	Erosion susceptibility & stability of fossil-bearing substrates, potential impacts to buried fossils from root activity	X		
3.01.007	Changes in surface height of fossil-bearing substrates in relation to benchmark height	Erosion rate of fossil-bearing substrates	X		
3.01.008	Spatial distribution & density of trails & roads in relation to exposures of fossil-bearing substrates	Erosion susceptibility, fossil accessibility	X	X	X
3.01.009	Rates of fossil loss & exposure by erosion on fossil-bearing substrates	Indicate rates of natural fossil loss and exposure	X	X	X
3.01.010	Relative condition of individual fossil-resource sites, defined on basis of natural & anthropogenic risk factors	Site-specific indicator of fossil-resource condition	X	X	X
3.01.011	Cumulative proportions of fossil-bearing surface	Overall indicator of fossil-resource condition within a	X		

Table 12 cont.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
	exposures in different resource-condition classes, defined on basis of natural & anthropogenic risk factors	park			
3.01.012	Commercial market value of fossils in dollars	Indicates incentive for fossil theft	X		
3.01.013	Amount of published material on fossils in park (total number)	Method of tracking research attributable to pemitted and unpermitted fossil collections	X		
3.01.014	Geologic features (e.g., arches) -- weathering / erosion rates of visited features in relation to comparable controls	Potential impacts of visitation on geologic features	X		
Stressors					
4.01.001	Park use -- park visitation by month (total number of visitors)	Potential impacts to multiple resources	X	X	X
4.01.002	Park use -- terrestrial visitor-use days by location, month & type of activity	Potential impacts to multiple resources	X	X	X
4.01.003	Park use -- watercraft-use days by month & type of watercraft	Potential impacts to multiple resources	X	X	X
4.01.004	Park use -- frequency, location, timing & type of audible overflights	Potential impacts to sensitive wildlife, natural soundscape, wilderness experience	X		
4.01.005	Park use -- frequency, location, timing & type of visible overflights	Potential impacts to wilderness experience	X		
4.01.006	Park use -- frequency of resource theft, poaching, and/or vandalism (total number of documented cases)	Impacts to multiple resources (e.g., wildlife, paleontological resources, rare plants)	X	X	X
Stressors					
4.01.007	Park use -- frequency and character of reported human-wildlife interactions	Potential impacts to wildlife resources	X		
4.01.008	Permitted livestock use -- location, timing / duration, and intensity of use	Potential impacts to multiple resources	X	X	X
4.01.009	Permitted livestock use -- location, type, and condition of livestock-related infrastructural developments	Drives distribution of livestock & other animals; potential impacts to water resources, watershed hydrologic function, & associated native communities	X	X	X
4.01.010	Other permitted uses -- location, timing, and type of activity	Potential impacts to multiple resources	X	X	X
4.01.011	Unpermitted livestock use -- frequency, location, timing / duration, and intensity of use	Potential impacts to multiple resources	X	X	X
4.01.012	Other non-compliant uses -- frequency, location, timing / duration, and type of activity	Potential impacts to multiple resources	X	X	X
4.01.013	Feral animals within park -- distribution & abundance by type of animal	Potential impacts to multiple resources	X	X	X
4.01.014	Diseases -- frequency & extent of occurrence within park, by type	Potential impacts to multiple resources	X		
4.01.015	Diseases -- frequency & extent of occurrence within surrounding region, by type	Potential impacts to multiple resources	X	X	X

Table 12 cont.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
4.01.016	Park operations -- location, timing & type of new infrastructural development -- NPS & other entities	Potential impacts to multiple resources	X	X	X
4.01.017	Park operations -- location, timing & type of infrastructural maintenance activities (including roads & trails) -- NPS & other entities	Potential impacts to multiple resources	X	X	X
4.01.018	Park operations -- location, timing & type of weed-control activities	Potential impacts to multiple resources	X	X	X
4.01.019	Right-of-way claims (RS2477) -- location & status	Potential impacts to multiple resources	X	X	X
4.01.020	Livestock use on adjacent lands -- location, timing / duration, and intensity of use	Potential impacts to within-park resources, watershed hydrologic function, water quality	X		
4.01.021	Logging activities on adjacent lands -- location / extent, timing and type of operation	Potential impacts to within-park resources, watershed hydrologic function, water quality	X	X	X
4.01.022	Geophysical / mineral exploration and development on adjacent lands -- location / extent, timing and type of operation	Potential impacts to within-park resources, watershed hydrologic function, water quality	X	X	X
4.01.023	Predator-control / hunting activities on adjacent lands (e.g., mountain lions, ungulates, prairie dogs)	Direct mortality, altered predator-prey relationships, altered habitat-use patterns	X		
4.01.024	Pesticide applications -- frequency of occurrence within park airsheds and watersheds, by type of compound	Potential impacts to multiple resources	X	X	X
4.01.025	Downstream & upstream distance of dams	Flow regime change	X	X	X
4.01.026	Upstream & downstream density of water diversions	Reduction of flows or change in baseflow and hydrograph	X	X	X
4.01.027	Permitted water withdrawals from upstream & downstream water diversions (equate to flow reduction)	Reduction of flows or change in baseflow and hydrograph	X	X	X
4.01.028	River regulation / reservoir operation	Change in hydrograph - daily, monthly and yearly	X	X	X
4.01.029	Small impoundments in watershed -- no. of acres	Change in drainage gradient, siltation, establishment of exotics	X	X	X
4.01.030	Groundwater extraction in watershed-irrigation	Threats to springs, seeps, and associated biota	X	X	X
4.01.031	Groundwater extraction in watershed-domestic	Threats to springs, seeps, and associated biota	X		
4.01.032	Groundwater extraction in watershed-municipal	Threats to springs, seeps, and associated biota	X	X	X
4.01.033	Water withdrawals -nonpermitted	Reduction of flows or change in baseflow and hydrograph	X		
4.01.034	Hydropower calls	Rapid fluctuation of flow regime and change in reservoir elevation	X	X	X
4.01.035	Return flows from irrigation	Potential siltation, nutrient inputs, impact to biota	X		
4.01.036	Instream flow rights (lack of recognition)	Continued flow reduction	X		
4.01.037	Flood irrigation management	Dewatering of riverine systems	X		
4.01.038	Calls from downstream senior water rights owners	Maintenance of baseline aside from natural hydrograph	X	X	X
4.01.039	Water exchanges in reservoirs - wet & dry water	Potential to change natural hydrograph	X		
4.01.040	Changes in points of diversion for permitted water	Potential to change natural hydrograph	X	X	X

Table 12 cont.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
	withdrawal				
4.01.041	Changes in types of beneficial use - irrigation, municipal, domestic, wildlife	Potential to change natural hydrograph	X	X	X
4.01.042	Changes in type of water right - diversion versus storage	Potential to change natural hydrograph	X	X	X
			310	164	126

Literature Cited

Chapin, F. S., III, M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. The American Naturalist 148:1016-1037.

Dale, V. H., and S. C. Beyeler. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1:3-10.

Davis, G. E. 1997. General ecological monitoring program design, implementation, and applications: a case study from Channel Islands National Park, California in J. K. Reaser and F. Dallmeier, eds. Measuring and monitoring biodiversity for conservation science and adaptive management. Smithsonian Institution, Washington, D.C.

Evenden, A., M. Miller, M. Beer, E. Nance, S. Daw, A. Wight, M. Estenson, and L. Cudlip. 2002. Northern Colorado Plateau Vital Signs Network and Prototype Cluster, Plan for Natural Resources Monitoring: Phase I Report, October 1, 2002. [Two volumes]. National Park Service, Northern Colorado Plateau Network, Moab, UT.

Herrick, J. E., W. G. Whitford, A. G. DeSoyza, and J. W. Van Zee. 1995. Soil and vegetation indicators for assessment of rangeland ecological condition. North American workshop on monitoring for ecological assessment of terrestrial and aquatic ecosystems. Monticello, Texcoco, México, Gen. Tech. Rep. RL-GTR-284, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, 18-12 September 1995.

Herrick, J. E., J. R. Brown, A. J. Tugel, P. L. Shaver, and K. M. Havstad. 2002. Application of soil quality to monitoring and management: paradigms from rangeland ecology. Agronomy Journal 94:3-11.

Kurtz, J. C., L. E. Jackson, and W. S. Fisher. 2001. Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development. Ecological Indicators 1:49-60.

Linstone, H. A., and M. Turoff, eds. 1975. The Delphi method: Techniques and applications. Addison-Wesley, Reading, MA. (http://www.is.njit.edu/pubs/delphibook/). Accessed 19 November 2004.

Noss, R. 1990. Indicators for monitoring biodiversity. Conservation Biology 4:355-364.

Oliver, I. 2002a. An expert panel-based approach to the assessment of vegetation condition within the context of biodiversity conservation: Stage 1: the identification of condition indicators. Ecological Indicators 2:223-237.

Oliver, I. 2002b. Introduction to an expert panel based approach for the assessment of vegetation condition within the context of biodiversity conservation. Ecological Management & Restoration 3:227-229.

Pyke, D. A., J. E. Herrick, P. L. Shaver, and M. Pellant. 2002. Rangeland health attributes and indicators for qualitative assessment. Journal of Range Management 55:584-597.

Tegler, B., and M. A. Johnson. 1999. Selecting core variables for tracking ecosystem change at EMAN sites. Final report to Environment Canada Ecological Monitoring and Assessment Network (EMAN), Guelph, Ontario. Geomatics International Inc., Burlington, Ontario. (http://www.eman-rese.ca/eman/reports/publications/2000_eman_core_variables/). Accessed 19 November 2004.

Whitford, W. G. 1998. Validation of indicators. Pages 205-209 in D. J. Rapport, R. Costanza, P. R. Epstein, C. Gaudet, and R. Levins, editors. Ecosystem health. Blackwell Science, Malden, MA.

Whitford, W. G. 2002. Ecology of desert systems. Academic Press, San Diego.